51. IWK

Internationales Wissenschaftliches Kolloquium
International Scientific Colloquium

PROCEEDINGS

11-15 September 2006

FACULTY OF ELECTRICAL ENGINEERING AND INFORMATION SCIENCE

INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING - DEVICES AND SYSTEMS, MATERIALS AND TECHNOLOGIES FOR THE FUTURE

TECHNISCHE UNIVERSITÄT
ILMENAU

Impressum

Herausgeber: Der Rektor der Technischen Universität Ilmenau
Univ.-Prof. Dr. rer. nat. habil. Peter Scharff

Redaktion: Referat Marketing und Studentische Angelegenheiten
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Fakultät für Elektrotechnik und Informationstechnik
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Redaktionsschluss: 07. Juli 2006

Technische Realisierung (CD-Rom-Ausgabe):
Institut für Medientechnik an der TU Ilmenau
Dipl.-Ing. Christian Weigel
Dipl.-Ing. Marco Albrecht
Dipl.-Ing. Helge Drumm

Technische Realisierung (Online-Ausgabe):
Universitätsbibliothek Ilmenau
ilmedia
Postfach 10 05 65
98684 Ilmenau

Verlag:
isle
Verlag ISLE, Betriebsstätte des ISLE e.V.
Werner-von-Siemens-Str. 16
98693 Ilrnenau

ISBN (Druckausgabe): 3-938843-15-2
ISBN (CD-Rom-Ausgabe): 3-938843-16-0

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=12391

51st Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
September 11 – 15, 2006

A. Marschall, F. Berger

Ligthning Current Study of Miniature Circuit Breakers

Abstract

Miniature circuit breakers (MCBs) are designed to protect installations against overload and short-circuit. They react sensitively to transient currents and stresses caused by atmospheric discharges like direct or indirect ligthning strokes. Due to the almost unknown behaviour of MCBs on ligthning and surge currents, systematic tests are in progress in order to determine the physical processes during the stresses.

1 Introduction

Low voltage switching devices can be exposed to different lightning currents. These currents cause electrical, mechanical and thermal stresses and may affect the operational reliability. In consequence of the increasing use of overvoltage protective devices there are interactions between the MCBs and the surge protective devices. As a result the MCBs react sensitively to transient currents and intermittent failures [1]. The knowledge of lightning current stresses and the behaviour of the MCBs is essential to comply with requirements for power quality and availability. It is mandatory for the effective coordination of overcurrent and overvoltage protective devices.

A surge current with a wave form 8/20 µs (relatively poor in energy) was basically used to investigate the lightning current behaviour of MCBs. These currents result from galvanic or inductive coupling due to a distant lightning stroke (indirect lightning effects) or switching operations of surge protective devices [2]. As a result of direct lightning impact there are also high-energy surge currents. These are the so called lightning impulse current and partial lightning currents represented by the wave form 10/350 µs.

Several MCBs with different tripping characteristics (B, C) and nominal currents (16 A, 32 A) from different manufacturers were selected for the examinations.

They are basically used for domestic and small commercial installations, mostly in the sub-installation. Several selective back-up MCBs, used for domestic, commercial and small industrial installations, were tested in reference to their lightning current behaviour, too.

2 Experimental setup

At first the tripping behaviour for the aforesaid surge current wave forms was determined. This current, herein after referred to as the tripping current, is specified as the peak value of the surge current the MCB trips. Special surge current generators were used to produce the two current wave forms. Basically they use a capacitor discharge into a low-inductive RLC-circuit. The samples have hardly any reactions on the pulse current by the high charging voltages over 5 kV [2]. The experimental setup to determine the tripping currents for the 8/20 µs surge current is shown in Fig. 1.

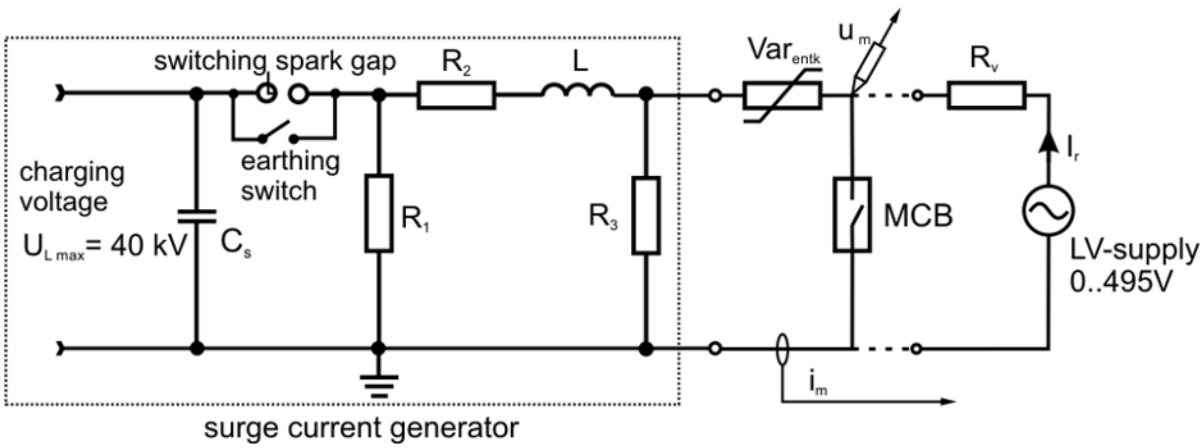

Fig. 1: Experimental setup for determination of tripping currents

To determine the tripping current, the surge current was increased until the MCB opened. The current and voltage over the MCB were measured simultaneously. Fig. 2 shows examples of typical voltages caused by the current wave forms 8/20 µs and 10/350 µs.

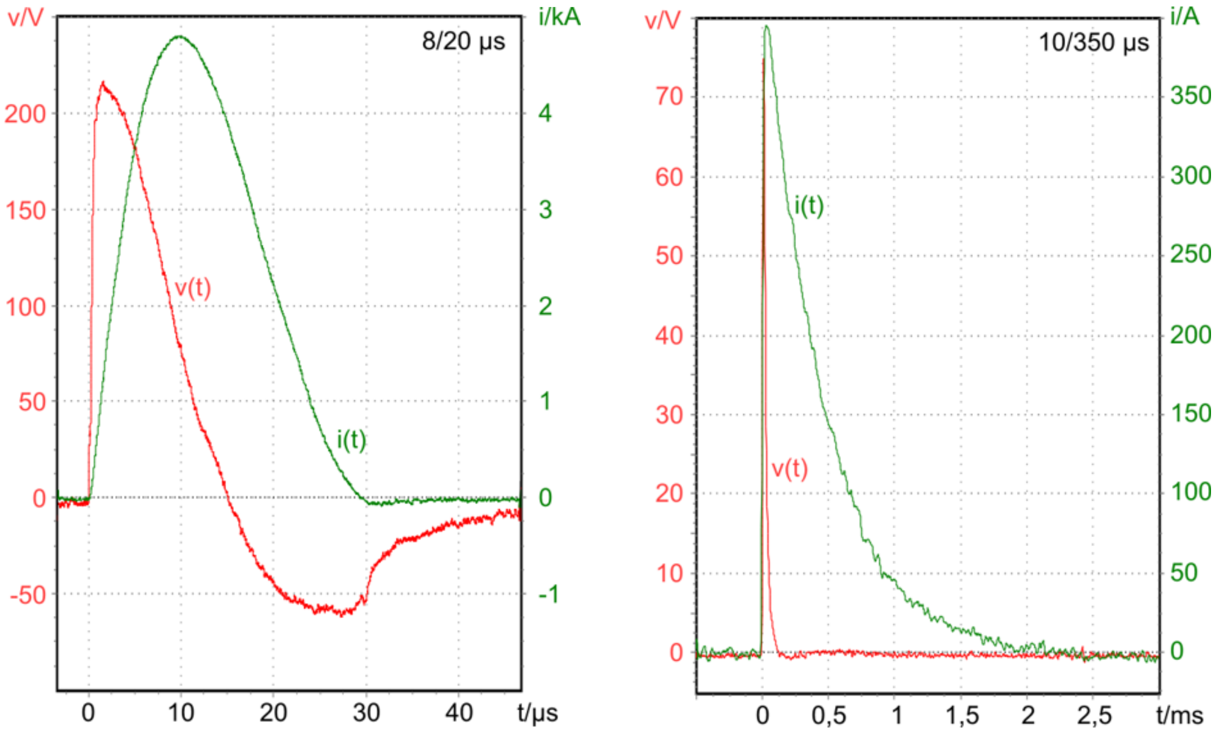

Fig. 2: Typical current and voltage versus time for a surge current (8/20 µs) and a lightning impulse current (10/350 µs) applied to MCB

The moment the MCB opens can not be seen in the voltage diagram for the surge current (8/20 µs), because the tripping takes place a long time after the pulse ($t_{cut\ off}$ = 1 .. 2 ms). There is no current flow at that time, so the tripping is currentless and no arc occurs. The 50 Hz nominal current of the MCB was applied to detect the time when the MCB opens, like shown in Fig. 1. The resulting arc voltage at contact seperation could be measured.

3 Results

Due to the specific constructions, the different designs and the variation of the tripping characteristics complying with the IEC/EN 60898 standard, there is a wide range of tripping currents. The tripping currents for both wave forms are shown in Fig. 3. As seen in Fig. 3 the MCBs are relative insensitive to the surge current (8/20 µs). So the values of tripping currents are relatively high (approximately 30-times higher) in comparison to the lightning impulse current (10/350 µs). This effect can be traced back to the long pulse duration of the lightning impulse current (10/350 µs). The MCBs contain a tripping coil to interrupt the current in the case of a short-circuit. The current causes a magnetic force so the core slug moves and unlocks the actuator mechanism.

The magnetic force and the force impulse respectively are not only proportional to the square of the current value, but also to the pulse duration. Therefore the tripping current is much lower for the lightning impulse current (10/350 µs).

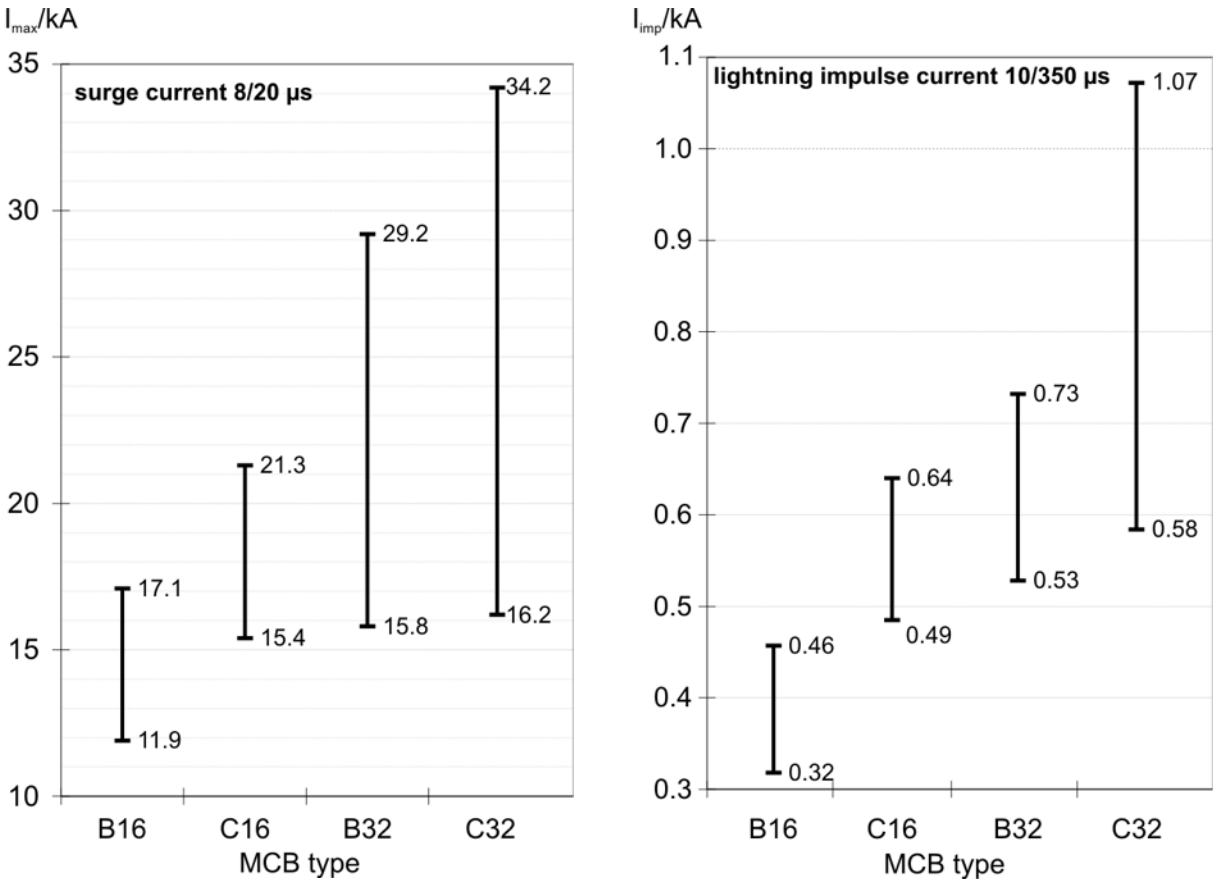

Fig. 3: Ranges of tripping current of the tested MCBs

The selective MCBs do not trip during the tests with the surge current (8/20 µs), because of their different construction (only a bimetallic strip can trip the actuator mechanism). However the electrical insulation can not withstand at a peak value of 36 kA and internal sparkover occurred. The voltage across the coil rises above 5.5 kV. In contrast to the surge current (8/20 µs) the selective MCBs trip at a lightning impulse current (10/350 µs) at a value of 15 kA.

There are several reactions on the lightning currents due to the complex and different constructions. The physical effects and actions can be assigned to the functional components of the MCBs. The effects appear more or less depending on the type, tripping characteristic, nominal current and manufacturer. The observed pulse current effects are shown in Fig. 4.

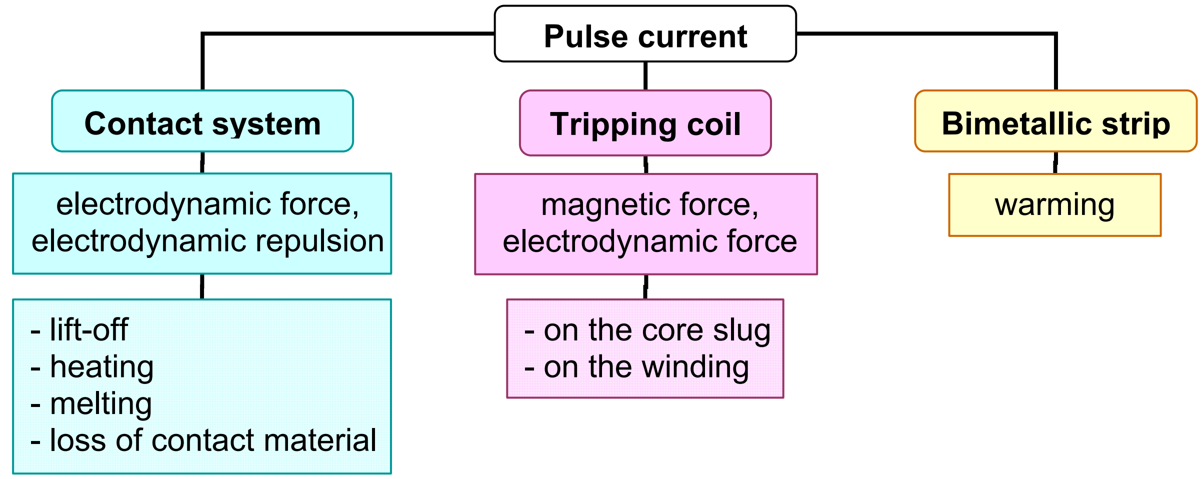

Fig. 4: Physical effects on the functional components for pulse current stresses

3.1 Effects at the contacts

As a result of the small contact area and the mechanical load, there are only few real contact spots [3]. The current density rises to very high values and the contact spots melt because of the current constriction. This happenes at a current peak value of about 7 kA (8/20 µs), depending on the contact material and the mechanical load. The deposit of energy is high enough to vapourise the molten metal. The generated pressure and the electrodynamic forces cause the splashing of molten metal out of the contact area during this process. Frequent surge currents cause aging of the contacts because the surface material will be removed and eroded. A comparison between new and eroded contact members is shown in Fig. 5. The surface of the moveable contact seems like the negative reproduction of the fixed contact.

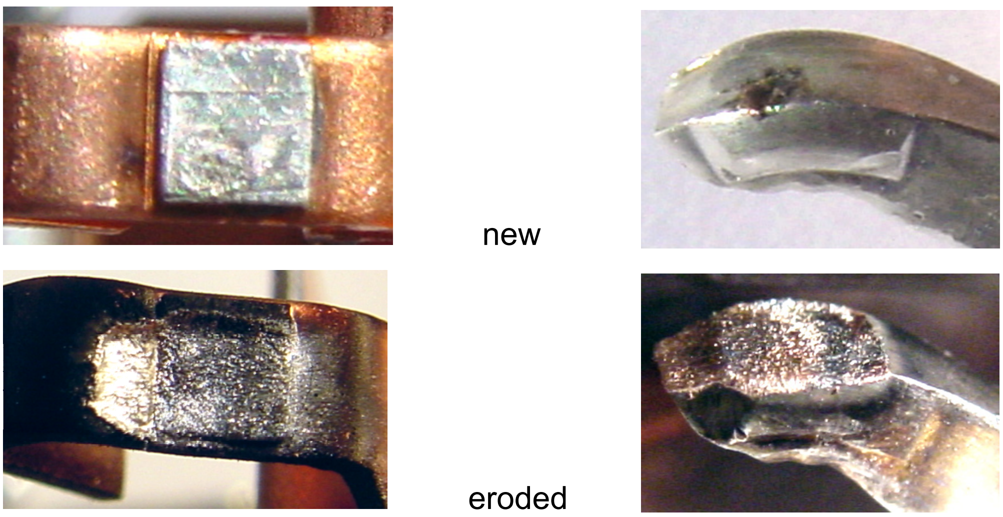

Fig. 5: Eroded contact members after 15 surge currents ($\hat{I}_{8/20\ \mu s}$ = 20 kA)

The splashing of hot molten metal can be visualised using a high-speed camera. The molten metal deposits on the wall of the arc chamber and the opposite arc rail as shown in Fig. 6.

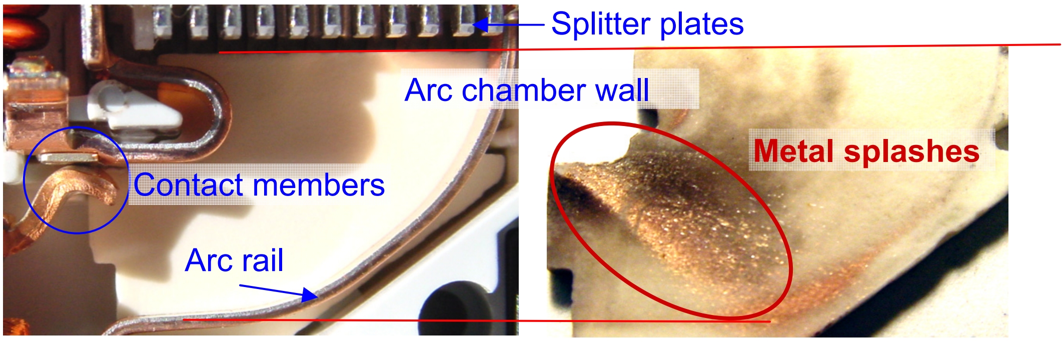

Fig. 6: Deposits of molten contact material on the arc chamber wall

3.2 Effects on the tripping coil

The acting magnetic force caused by the flowing current is a crucial factor in moving the core slug and tripping the MCB. Therefore both, the value of current and the pulse duration, are important.

Especially the surge current with the wave form 8/20 µs causes tripping coil deformation. This can reduce the operational reliability or destroy the tripping coil and therefore the MCB. This is a dangerous situation for the user and the installation, because the internal condition of the MCB is not always evident from the outside. Particularly the electrodynamic force on the coil winding must not be underestimated. The character of the damage depends on the construction of the coil, e.g. number of windings and wire diameter. It varies from slight deformation or expansion (changing the inductance and tripping characteristic) to breakage of a coil termination so that the electrical connection no longer exists.

3.3 Effects on the bimetallic strip

The bimetallic strip is not effected by the surge currents (8/20 µs), because the specific energy ($W/R = \int i^2 dt$) is not enough to heat the bimetal distinctly. The heating is also insufficient to release the mechanical actuator after multiple surges.

Only a lightning impulse current (10/350 µs) with a higher amplitude can produce enough heat to bend the bimetallic strip to trip the MCB. Such current values were only applied to the selective MCBs (as shown before), because the smaller MCBs could be destroyed.

4 Conclusion

For the best protection of electrical installation and a save uninterruptible operation of low-voltage power supply, it is necessary to know the lightning current behaviour of the switching devices. Moreover critical and unknown conditions of the MCBs can be avoided. It was possible to gain an overview of the behaviour and stress of MCBs during different pulse currents by means of the experimental tests. Further examinations need to be done on the physical effects and their dependency on the tripping device. The results provide a basis for better understanding and possible technical innovations.

Additional tests with combined stresses were made during the research activities. Real installation conditions were simulated and a surge current was applied to an operating MCB (at nominal current). The behaviour of the MCB in series to a surge protective device (SPD class II) was tested too. The typical parameters of the SPD provided the test criteria for the MCBs, e.g. the nominal discharge current (I_n) and the voltage protection level (U_P). The withstand against and ageing at frequent surge currents were determined in addition to the behaviour in a protective circuit.

This research project (FV-Nr 14209/B) is state-aided by the Federal Ministries of Economics and Labour (BMWA) and the German Federation of Industrial Research Associations "Otto von Guericke" (AiF).

References:

[1] www.zvei.de/index.php?id=1780
[2] Noack, F., Schönau, J., Brocke, R.: Einfluß der Blitzstromtragfähigkeit von Überstrom-Schutzeinrichtungen auf den Blitzschutz in Niederspannungs-Netzen, etz Heft 3-4, 1998
[3] Holm, R.: Electrical Contacts – Theory and Applications, Springer-Verlag Berlin Heidelberg New York, Reprint of the fourth edition 1967, 3rd printing 2000

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